A HIGH-GAIN CIRCULARLY POLARIZED Ka-BAND MICROSTRIP REFLECTARRAY

John Huang

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California 91109

KEY TERMS

Reflectarray antenna, microstrip, Ka-band, circular polarization

ABSTRACT

A half-meter, 32 GHz, circularly polarized microstrip reflectarray antenna has been developed. Excellent efficiency, good bandwidth, and low average sidelobe and cross-pol levels are achieved. It is believed that this is electrically the largest microstrip reflectarray (6924 elements) that has ever been developed, and it is the first time that circular polarization has been demonstrated using microstrip elements,

INTRODUCTION

A microstrip reflectarray antenna consists of two basic elements: an illuminating feed and a thin reflecting surface that can be either flat or slightly curved. On the reflecting surface, there are many isolated microstrip patches without any power division network. The feed antenna illuminates these microstrip patches which are designed to re-radiate the incident field with phases that are required to form a planar phase front. The name "reflectarray" represents an old technology [1]. However, the low-profile printed microstrip reflectarray is a fairly new concept [2,3,4,5,6], which combines some of the best features of the microstrip array technology and the traditional parabolic reflector antenna. It has the low profile and beam scanning [7] capabilities of the microstrip array and the large aperture with low insertion loss characteristic of a parabolic reflector. There are many forms of printed reflectarray, such as the ones that use circular ring elements [8,9] and crossed-dipole elements [10]. This article deals only with microstrip patch elements,

Currently, the printed microstrip patch reflectarray comes in two slightly different forms. One uses identical patches with different-length phase delay lines attached to compensate for the different spatial phase delays [2,4,6] from the feed to the elements, The second form uses variable-size patches to achieve the required phase delays without any transmission line attached [5]. Recently, an X-band microstrip reflectarray [11] of the first form having a diameter of 73 cm has been developed. It demonstrated relatively high efficiency of 70°/0 with peak gain of 35 dBi. Although it has dual-linear and dual-circular polarization capabilities, only linear polarization was demonstrated. A 27 GHz microstrip reflectarray of the second form was recently reported [12], It has a diameter of 23 cm and achieved a gain of 31 dBi with an efficiency of 3 10/o. Although dual-linear and dual-circular polarizations can also be achieved by this form of reflectarray, only linear polarization result was reported. One of the reasons that this second form of reflectarray resulted a relatively low efficiency at the Ka-band frequency is because its efficiency is more susceptible to the fabrication tolerance of the patch dimensions, since the desired phase delays are achieved by varying these dimensions.

This article presents a Ka-band microstrip reflectarray of the first form with a half-meter diameter. It is circularly polarized and achieved a peak efficiency of 69% with a gain of 42.75 dBic. It is believed that, to date, this microstrip reflectarray's aperture is electrically the largest and is the only one that has demonstrated circular polarization,

ANTENNA DESCRIPTION

A 32 GHz microstrip reflectarray has been developed for NASA/JPL future microspacecraft applications. A photograph of this antenna is given in Figure 1. It was designed based on conventional array theory and parabolic reflector technique [3,4,6], It has an f/D ratio of 0,75. "f", being 37.2 cm long, is the focal length and is the distance between the phase center of the feed horn and the radiating plane of the patch elements. "D" is the diameter of the radiating aperture and is equal to 50 cm. Each patch element, illustrated in Figure 2, has a square dimension of 2.946 mm. This dimension was determined through the design and test of a single patch element for a resonant frequency centered at 32.0 GHz. There are a total of 6,924 patch elements across the complete aperture with an element spacing of 0.58 free-space-wavelength (λ_o). These patches are etched on a 0.254 mm thick Duroid substrate having a relative dielectric constant of 2.2. in Figure 2, the width of the attached phase delay lines is 0.075 mm which was designed to have an impedance of 154 ohms. The input impedance of the square patch is 230 ohms. It is not very critical to have the impedance of the phase delay line matched exactly to that of the patch. However, the line impedance should be as close to the input impedance of the patch as possible so that mismatch and multiple reflections within the line are minimized. Certainly, fabrication tolerance and reliability issues should be considered in designing the width of these lines. Too thin a line can be easily scratched or delaminated. In addition, due to etching tolerance, it would be difficult to maintain uniformity of line width across the large aperture if the lines were too thin, The etching tolerance achieved across the aperture for both patches and phase delay lines is ± 0.008 mm. A great deal of effort was spent in assuring the achievement of this tolerance. One way that eased the achievement of the desired tolerance was by selecting the thinnest available copper thickness which is 0.009 mm (1/4 ounce per square foot).

To assure good antenna efficiency and no surprising high sidelobes, the radiating aperture of the reflectarray should maintain a flatness of at least 1/30th of a wavelength. In order to achieve this flatness (0.3 mm) across the half-meter aperture, the thin Duroid substrate is supported by a 1.9 cm thick aluminum honeycomb panel. Each side of the honeycomb panel is bonded to a 0.5 mm thick graphite epoxy face sheet. The etched copper-clad Duroid substrate is then bonded onto the face sheet. The feed horn is precision fastened above the honeycomb panel by four aluminum rods of 1 cm diameter. The feed horn, which is a circularly polarized, corrugated conical horn, is mounted such that it can be moved axially for fine focal point adjustment. The overall antenna mass is 1.65 Kg. It is estimated that, with additional effort, the antenna mass can be reduced to 1Kg or less. The feed horn was designed to illuminate the reflectarray aperture with a -9 dB edge taper. The corrugations in the horn were designed to minimize the sidelobe level and, thus, the spillover loss. This feed horn has a -3 dB beamwidth of 41 -deg and a -9 dB beamwidth of 69-deg. Its sidelobes are well below -30 dB and the cross-pol radiations are lower than -35 dB within the main beam region.

MEASUREMENT RESULTS

The measured radiation pattern of the microstrip reflectarray at 32,0 GHz is presented in Figure 3. It shows a peak sidelobe of -22 dB and all the other sidelobes, except the first two, arc well below -30 dB. This indicates that the backscattered component fields (from patches, phase delay lines, edges, etc.) arc significantly lower than the re-radiated co-pol field. It also indicates that the patches arc well matched in impedance to the phase delay lines and the fabrication accuracy is well controlled. The first adjacent high sidelobes arc believed to be caused by the blockage of the feed horn structure. Except within the main beam region, all the cross-pol radiations are well below **-40** dB. This well behaved cross-pol radiation is also the results of good impedance matching and excellent fabrication accuracy. The relative high cross-pol of **-22** dB in the main beam is caused by the co-phasal behavior of the cross-pol components in all the patches and the cross-pol component in the feed horn. It should be noted that the cross-pol component fields, similar to the co-pol fields, should all be coherently directed to the same direction by the same set of phase delay lines. This coherently directed cross-pol beam can be reduced by using the technique presented in reference 11,

At 32.0 GHz, the measured -3 dB beamwidth of the antenna is 1.2-deg and the antenna gain is 41.75 dBic which corresponds to an overall antenna efficiency of 53%. The patterns and antenna gains were also measured over the frequency range between 31.0 GHz and 33.0 GHz. All the patterns across this frequency range, except minor degradations, have features similar to those given in Figure 3. Over this frequency range, the highest gain of 42.75 dBic was measured at 31,5 GHz, which translates to an efficiency of 69°/0. The measured antenna gain and efficiency versus frequency curves arc given in Figure 4 which shows an oscillatory response. It is believed that, in addition to the resonance of the patches, some of the phase delay lines also become resonant at a particular frequency since they have dimensions similar to those of the patches. The resonances of these lines add in-and-out of phase with the resonance of the patches over the above frequency range and thus form the oscillatory behavior, To avoid such an oscillatory feature, the phase delay lines could be placed behind the ground plane in an additional substrate layer. Figure 4 shows a ±1 dB gain (around a nominal gain of 41.75 dB) bandwidth of 1.0 GHz and a -3 dB gain (from the peak gain of 42.75 dB) bandwidth of 1.8 GHz (5.60/0). These bandwidths are considered quite good for telecommunication applications at Ka-band. Wider bandwidth can be achieved by r-e-designing the radiating patches or by using time delay lines instead of the phase delay lines.

CONCLUSIONS

Relatively good antenna efficiency and wide bandwidth have been achieved for a Ka-band circularly polarized microstrip reflectarray. The antenna radiated excellent sidelobe and cross-pol levels. These good antenna performances arc the results of careful design of the feed horn, appropriate impedance matching of the phase delay line to the patch, and accurate fabrication of the antenna structure.

ACKNOWLEDGMENTS

The research described in this article was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. The author wishes to express appreciation to Gregory Boreham, John Cardone, and Gregory Hickey for their excellent fabrication and assembly skills and to Robert Beckon and William Pickett for their dedicated measurement efforts.

REFERENCES

1.11. G. Berry, et al, "The Reflectarray Antenna," IEEE Trans. Antennas and Propagat., Vol. AP-11, Nov. 1963, pp. 645-6S1

2. R. E. Munson and H. Haddad, "Microstrip Reflectarray Antenna for Satellite Communication and RCS Enhancement or Reduction," US Patent 4,6 S4,952, Aug. 1987.

3. J. Huang, "Microstrip Reflectarray Antenna for the SCANSCAT Radar Application," JPL Publication 90-45, Nov. 1990.

4. J. Huang, "Microstrip Reflectarray," IEEE AP-S Int. Symp. Digest, June 1991, pp. 612-615.

5. D. M. Pozar and T. A, Metzler, "Analysis of a Reflectarray Antenna Using Microstrip Patches of Variable Size," Electronics Letters, April 1993, pp. 657-65S.

6. J. Huang, "Analysis of a Microstrip Reflectarray Antenna for Microspacecraft Applications," JPL TDA Progress Report 42-120, Feb. 1995, pp. 153-172,

7. R. D. Javor, X. D. Wu, and K. Chang, "Beam Steering of a Microstrip Flat Reflectarray Antenna," IEEE AP-S Int. Symp. Digest, June 1994, pp. 956-959.

8. F. S. Johansson, "Frequency-Scanned Reflection Gratings Consisting of Ring Patches," IEE Proceedings, Vol. 138, No. 4, Aug. 1991, pp. 273-276.

9. Y. J. Guo and S. K. Barton, "Phase Correcting Zonal Reflector incorporating Rings," IEEE Trans. Antennas and Propagat., Vol. 43, April 1995, pp. 350-355.

10. A. Kelkar, "FLAPS: Conformal Phased Reflecting Surfaces," Proceedings of the IEEE National Radar Conference, March 1991, pp. 58-62.

11. D. C. Chang and M. C. Huang, "Multiple-Polarization Microstrip Reflectarray Antenna with High Efficiency and Low Cross-Polarization", IEEE Trans. Antennas and Propagat., Vol. 43, Aug. 1995, pp. 829-834.

12. S. D. Targonski and D. M. Pozar, "Analysis and Design of Millimeter Wave Microstrip Reflectarrays," IEEE AP-S Int. Symp. Digest, June 1995, pp. 578-581.

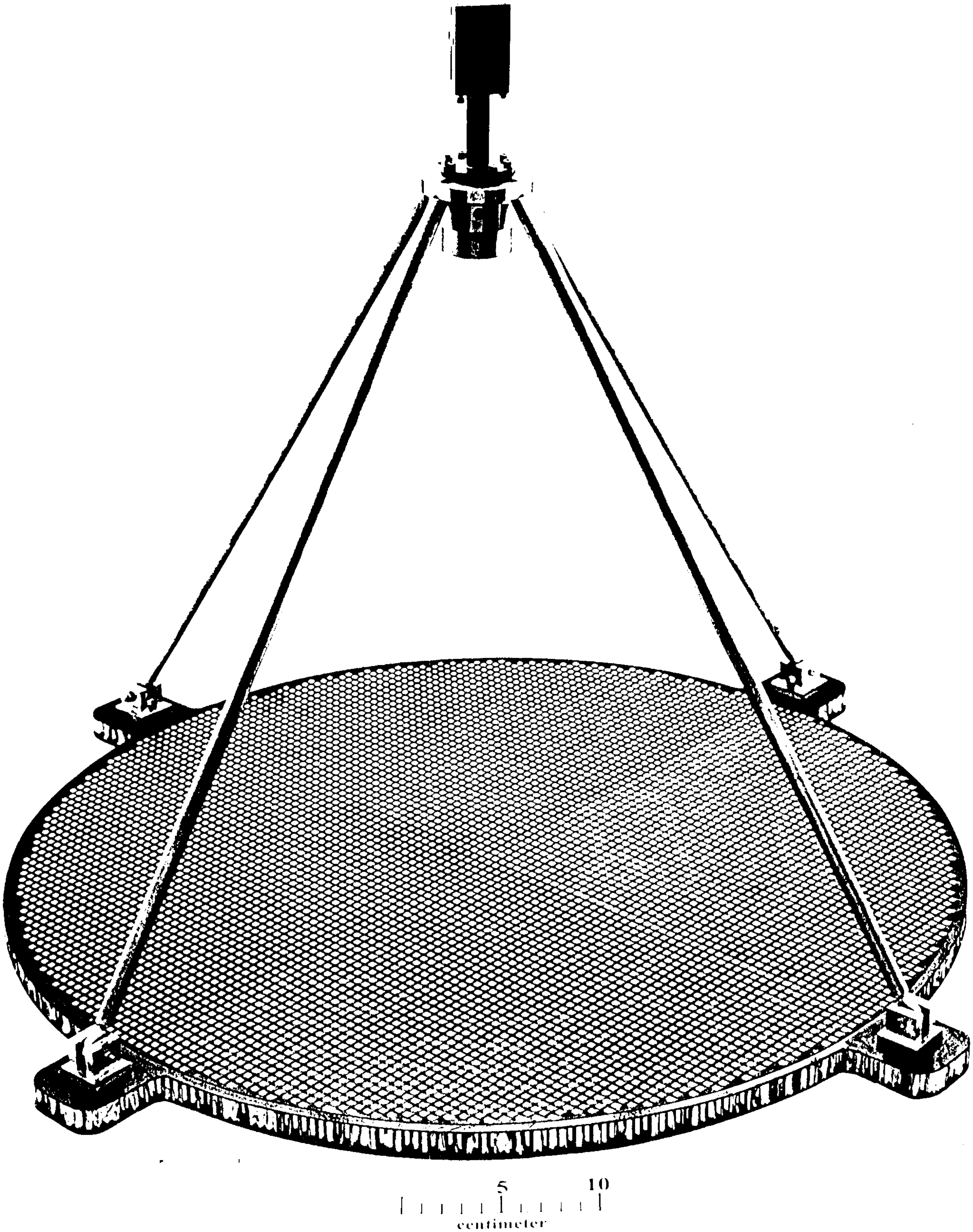

Figure 1. Photograph of the half-meter Ka-band microstrip reflectarray

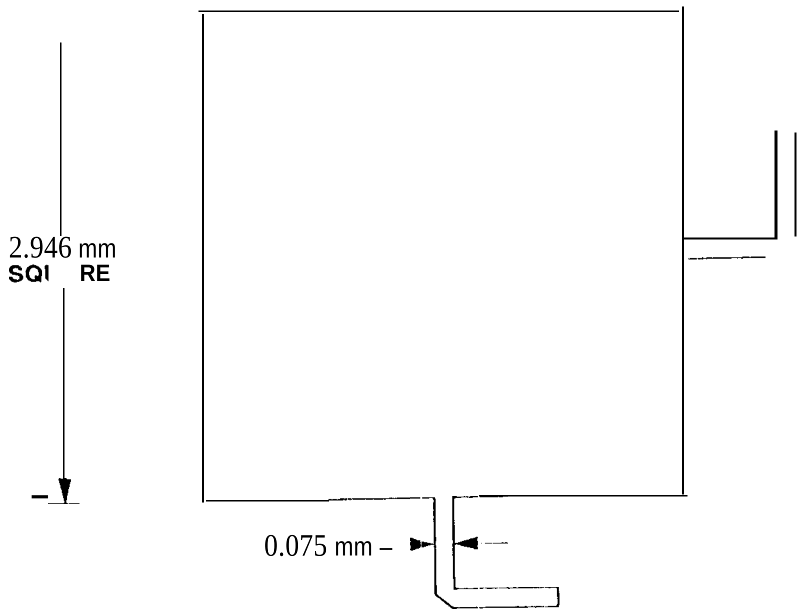

Figure 2. Single patch configuration of the microstrip reflectarray

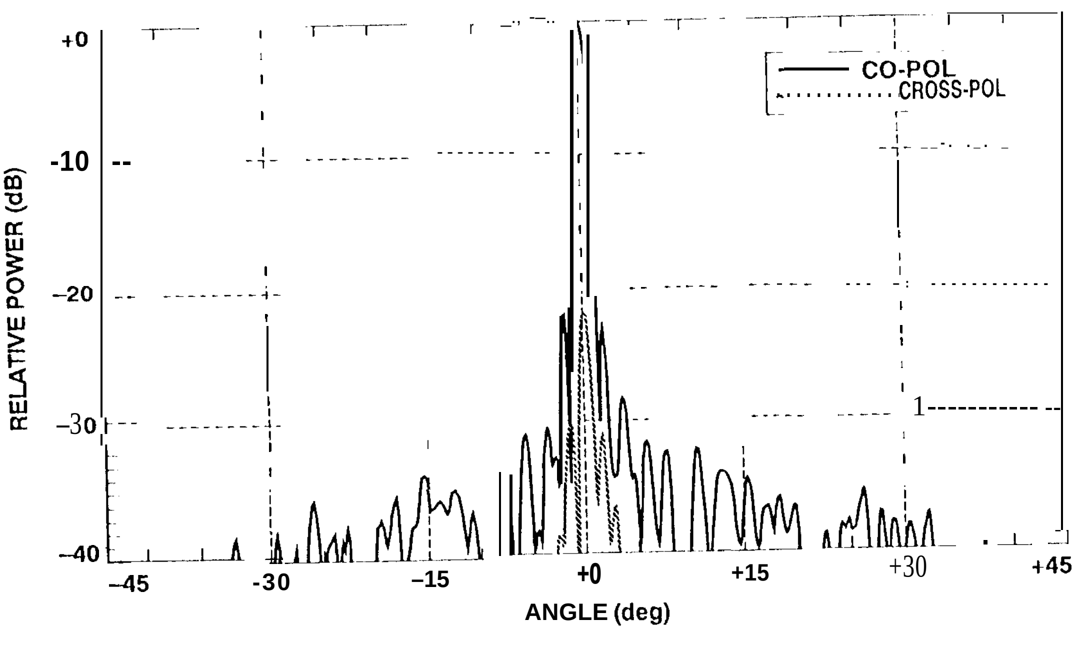

Figure 3. Measured radiation pattern of the microstrip reflectarray
at 32 GHz

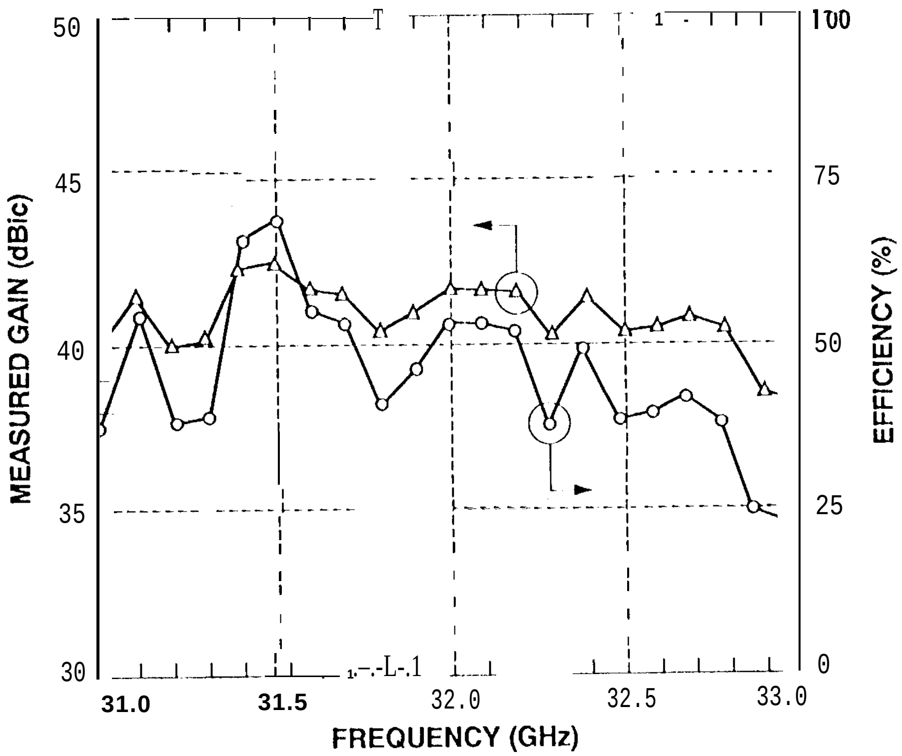

Figure 4. Plot of the measured antenna gain and efficiency versus frequency of the Ka-band microstrip reflectarray